SatVu

Imagery User Guide

V 1.0 – December 2024

Index

1. Introduction

This document describes SatVu's satellite thermal imagery products. It highlights SatVu's constellation and satellite collection capabilities, image processing specifications, and available product levels. It is intended for customers and users interested in working with SatVu's thermal imagery product offerings.

2. SatVu Constellation Overview

SatVu's HotSat satellite constellation is focused on delivering the highest-resolution thermal satellite imagery commercially available. HotSat-1 (2023) launched and successfully provided hundreds of usable mid-wave Infrared (MWIR) images before encountering an anomaly and becoming non-operational. SatVu is building HotSat-2 and HotSat-3 in 2025, working towards a planned constellation of 9 satellites delivering 10-20 revisits per day. Once launched, our satellites will resume collection of MWIR imagery to provide unique insight into small-scale features of the built and natural environments.

SatVu recognizes that satellite thermal imagery, particularly in the MWIR spectrum, offers a myriad of advanced capabilities that are instrumental in a range of applications, from environmental monitoring to defence and intelligence. With this understanding, the HotSat sensors are specifically designed to deliver the attributes outlined in Table 1.

Table 1 – Constellation overview

Satellite Name: First Generation - HotSat 1-3	
Ground Sample Distance (GSD)	3.5 m (nadir) to 6.4 m (45° ONA) at 500km nominal orbit
Sensor Type	Mid-Wave Infrared (MWIR)
Orbit/Inclination	Polar
Altitude	~500 km
Off-nadir angle (ONA)	0-45°
Revisit frequency at 40° latitude	1 day (45° max ONA) to 2 days (30° max ONA)
Spectral Bands (nm)	**Night**: 3700 - 4950 | **Day**: 4325 - 4950
Dynamic Range	14 bit
Geolocational Accuracy	30 m CE90
Swath (standard scene size)	4.5 km (across-track) x 3.5 km (along-track)*
Capacity	200 acquisitions per day

* Projected scene will vary depending on angle

3. Data Product Introduction

Imagery from the HotSat constellation is collected at a rate of 25 frames during the 1 second imaging sequence in the mid-wave thermal infrared band. The data is available in three primary product levels to cater to diverse user needs, each designed to offer different levels of processing and analysis capability.

3.1 Thermal L2 Visual

For users requiring a product optimised for immediate visual interpretation, the **Thermal L2 Visual** product offers orthorectified imagery that has been corrected for non-uniformity, making it suitable for monitoring and decision-making in defence, disaster response, and general remote sensing applications. As part of the Thermal L2 Visual product bundle, in addition to a single frame, SatVu delivers a **Stacked Image** which applies radiometric corrections to all frames in an imaging sequence, co-registers them to a single orthorectified frame, and then calculates the median pixel value of the image stack to produce an image with reduced noise characteristics.

Figure 1 – Thermal L2 Visual single frame image

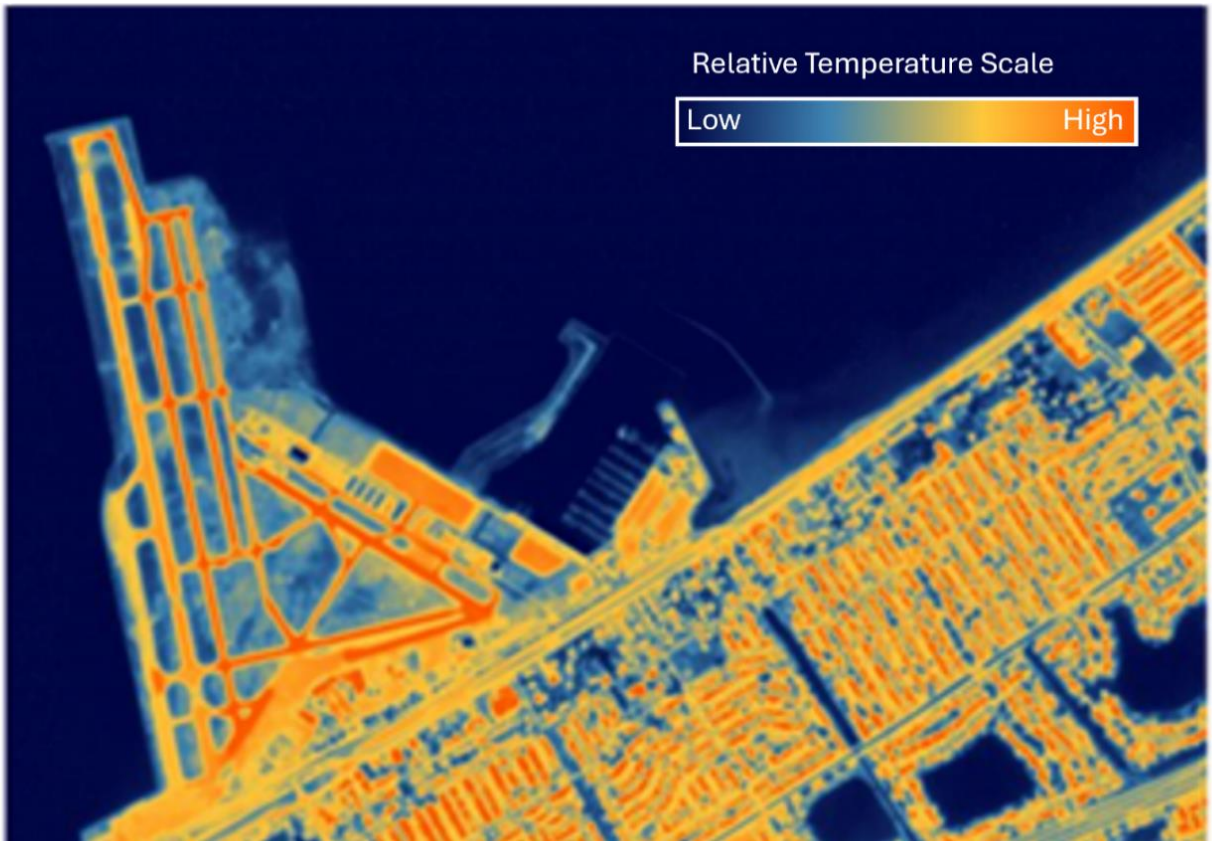

Figure 1 - Thermal L2 Visual single frame scene

Table 2 – Data Products and Use Cases

Thermal L2 Visual
Optimised for photo interpretation: • Pixel values delivered as Digital Numbers (DNs) • Representing relative radiance differences within a scene • Georeferenced 30 m CE90 • Ortho prototype available (including RPCs) **Value proposition:** • Signal photo interpretability • Improved geometry • Signal to asset detection **Use cases:** • High value industrial asset monitoring • Anomaly detection • Pattern of life interpretation

4. Data Product Processing

The default imaging mode for SatVu's HotSat sensor are 'snap videos' of the Earth consisting of 25 frames acquired over the course of 1 second. Forward-motion compensation is used to keep the satellite instrument pointed at the targeted ground location during each acquisition, enabling the capture of the same target from different angles.

Each frame is run through a radiometric processing procedure to convert the raw sensor data into frames with several radiometric adjustments applied to improve the image quality.

HotSat's at-nadir pointing accuracy starts with a 250 m CE90. We improve geolocational accuracy by utilizing the Near-Infrared (NIR) band from the Sentinel-2 Collection 1 Level-2A as the reference dataset for extracting image features, because of its absolute geolocational accuracy of less than 12 m at 95.5 % confidence[1]. More discussion on these accuracies and processing can be found within SatVu's Geometric Modelling User Guide.

[1] Collection 0 Level-1C. Sentinel Online (2021). https://sentinels.copernicus.eu/web/sentinel/sentinel-data-access/sentinel-products/sentinel-2-data-products/collection-0-level-1c.

The Copernicus DEM is a digital surface model encompassing a variety of products, one of which is the global 30 m pixel spaced GLO-30 product. The GLO-30 was selected for use within SatVu owing to its high-performance specifications and its global coverage. When using the GLO-30 product for orthorectification there are some limitations, owing to the difference in pixel sampling distance between the gridded product and a given HotSat acquisition. For users wishing to conduct their own orthorectification, SatVu recommends constraining acquisition parameters to lower off-nadir angles over mountainous terrain and high relief areas, sourcing higher resolution terrain models (at a pixel spacing roughly equal to that of the acquisition), and using the All-Frames Basic Product for custom processing scenarios.

Figure 2 – High relief areas

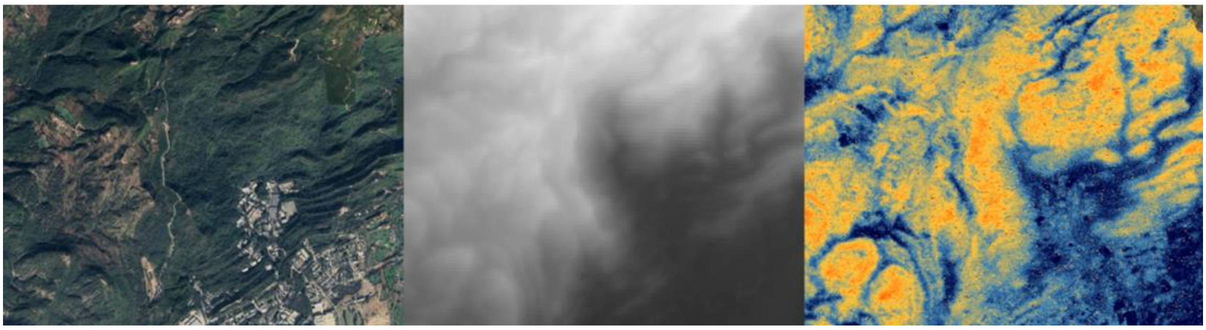

Figure 2 - In areas of high relief, and when acquisition off-nadir angle is high, orthorectification can lead to pixels and areas appearing stretched.

Figure 3 – Image processing flow

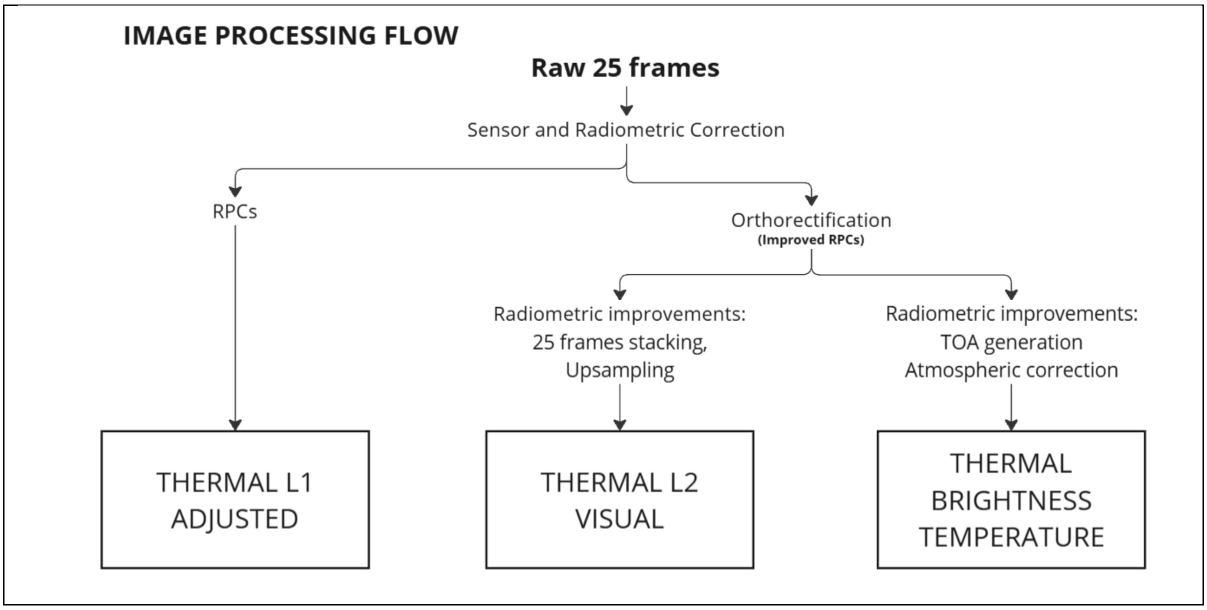

Figure 3 - Image processing flow

4.1 SatVu Data Product Processing Steps

Several image processing and geometric modelling steps are applied to SatVu imagery products as captured below in Table 3.

Table 3 – Data processing steps

Processing Step	Description	Thermal L2 Visual
Non-uniformity correction	Non-uniformity correction (NUC) coefficients are calculated from uniform images of the onboard calibrators. It adjusts raw sensor data to account for variations in the response of imaging sensor pixels to radiation.	✓
Flat field correction	Flat field correction is aimed at minimising signal variations and is performed by applying an 'offset adjustment', based on a cloud-free ocean views, to each individual image pixel signal. An example of the input and output of the flat field correction process is shown in Figure 4.	✓
Bad pixel detection and correction	Bad pixels are caused by individual detectors in the sensing focal plane array that exhibit erroneous responses to incident light. These pixel values cannot be corrected by the NUC (Non-Uniformity Correction) process. The signals from these corrected 'bad' pixels are interpolated in the final visual image, with their locations recorded in the Usable Data Mask (UDM) product for traceability and transparency.	✓
Top-of-Atmosphere (TOA) Radiance Conversion	A Thermal Self Emission (TSE) correction is made to the data using SatVu's calibrated conversion	
Atmospheric correction	Atmospheric correction is the process of correcting for the effects of the atmosphere on images taken by satellites or airborne sensors. This uses an atmospheric model and is susceptible to variation to the atmosphere during an acquisition. This process is important because atmospheric constituents like water vapor, aerosols, and gases can distort the signals captured by sensors.	
Tie point generation	To update the initial line-of-sight estimate, image tie points are detected on both the Sentinel 2 reference dataset and the given HotSat image acquisition. A feature detector[2] is run on both images, and candidate matches are filtered for outliers. **Note**: If tie points cannot reliably be generated, we fall back to the platform's pointing knowledge described in the Geometric Modelling Guide	✓

[2] Lowe, D.G. Distinctive Image Features from Scale-Invariant Keypoints. International Journal of Computer Vision 60, 91–110 (2004). https://doi.org/10.1023/B:VISI.0000029664.99615.94

Georeferencing	The generated tie points, camera distortion model, and a DEM are utilized to create a georeferencing solution	✓
RPC generation	An RPC model, encoding the georeferenced solution, is created	✓
Affine transformation	Tie points are used to fit an affine transformation between the sensor pixel coordinates and world coordinates, and	✓
Orthorectification	The fitted affine transformation is used to apply a georeferencing solution to the data and to create a map-projected image in a UTM coordinate system	✓
Stacking	Data frames are co-registered and combined into a single orthorectified image	✓

Figure 4 - Non-uniformity correction

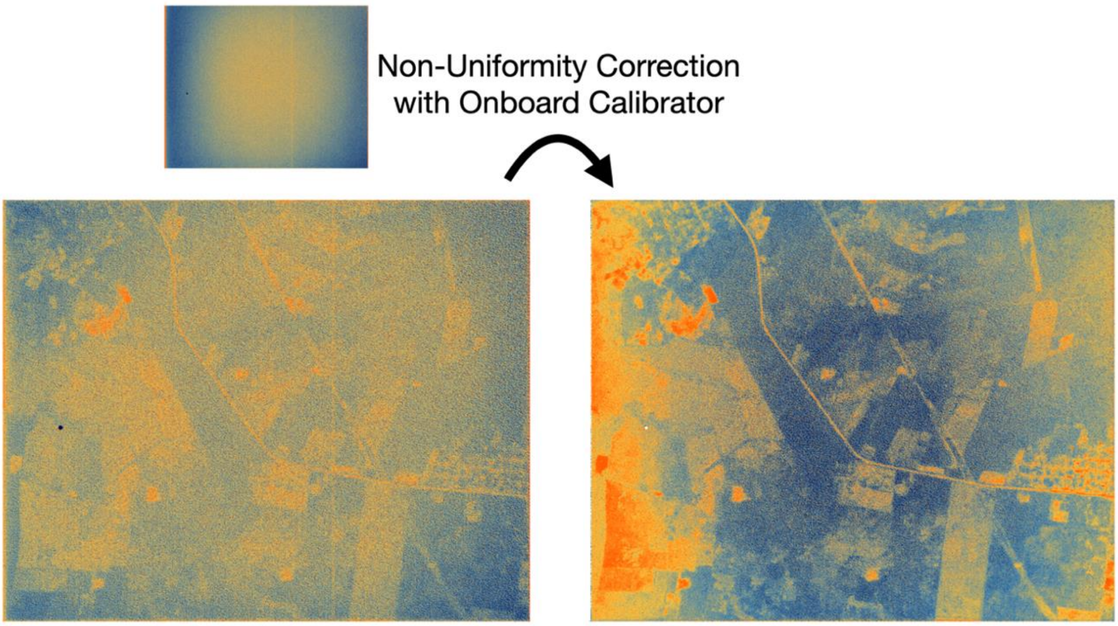

Figure 4 - Data from the onboard calibrator is used to conduct NUC, improving the visual appearance of the image, though still contributing some signal from the instrument's self-emission, which varies across each image and between image acquisitions.

Figure 5 - Flat field correction

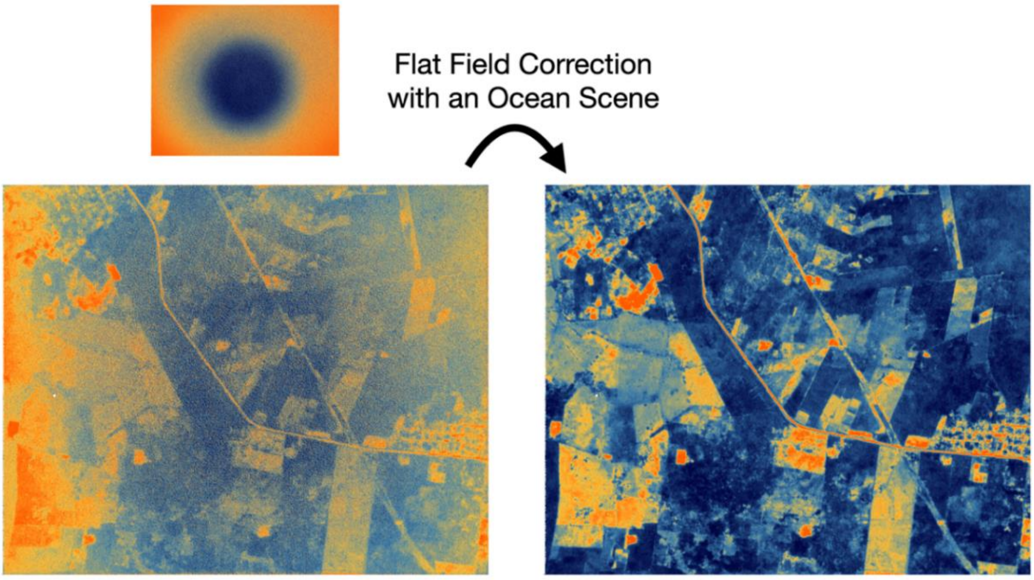

Figure 5 - An appropriate flat field image is selected to provide an additional offset adjustment that accounts for the effects of instrument thermal self-emission on the Earth view image, resulting in an improved radiometric correction beyond that of the NUC.

Table 4 - Usable data mask generation

Example: A pixel which is simultaneously “Bad Pixel” and “Not Data” will have a value of 9 = 1 + 8.

Value	Meaning	Description
1	**Bad Pixel**	This pixel had an unreliable response to light at the time of observation. If possible, an interpolated value is provided instead, otherwise the pixel will also be marked as 8 No Data.
2	**Cloud Cover**	The Earth’s surface is fully obscured by cloud.
4	**Saturated**	The light received pixel exceeded the maximum value that the detector on board the satellite can measure. The reported value is an underestimate of the true light level.
8	**No Data**	No value can be provided for this pixel. There are several causes of this, such as pixels being outside the imaged area, or bad pixels for which no interpolated value could be provided.

4.2 Geometric and Radiometric Validation

When performing the georeferencing refinement using tie points for each image, a series of automated quality checks are performed to reject unreasonable solutions. The refinement process is aborted if too few tie points are found, if the refined camera model produces a poor distribution of residuals among the tie points, or if the final image geometry differs too significantly from that predicted based on the viewing geometry.

The overall accuracy of the georeferencing process and of the camera models has also been validated. A database of reference images of urban scenes with dense sets of manual ground control points is used to ensure performance remains consistent across software versions. In addition, automated image matching to reliable third-party data sources such as Sentinel-2 is performed across a wider selection of the catalog, to evaluate performance in a wider range of circumstances.

The nighttime radiometric calibration has been validated against measurements from the VIIRS imager onboard Suomi-NPP. VIIRS is a multi-spectral instrument operated by NOAA; it possesses three MWIR bands which overlap spectrally with HotSat. Despite the much lower spatial resolution of VIIRS, we have been able to assemble a dataset of co-incident measurements between the two instruments covering a range of surface temperatures (from 270 K to 300 K). This cross-comparison study has shown that our radiometric calibration delivers mean absolute errors of nominally 8% at the bottom-of-atmosphere radiance level.

5. Thermal L2 Visual Product Specification

The Thermal L2 Visual product is radiometrically enhanced for visual interpretation, projected to a cartographic map projection. Pixel values are delivered as Digital Numbers (DN's) where each collection captures 25 frames that are stacked, and pixel values averaged to achieve better results taking advantage of the forward motion compensation capabilities of the satellite. Noise correction is applied through a speckle filter that adjusts noisy pixels by comparing them to surrounding values.

The geometric correction uses COPDEM Digital Elevation Models (DEMs) and tie points are generated against Sentinel-2 reference imagery to ensure accurate geometric corrections.

Orthorectification accuracy is maintained under optimal conditions but is not guaranteed for scenes with a view angle greater than 30°, captured above ±85° latitude, over varying terrain, or when large concentrations of clouds, snow, or water are present within the scene.

When orthorectification fails (due to angle, terrain, cloud, texture etc.) the fallback will rely on the application of unrefined AOCS data, providing an accuracy of roughly 200 meters.

Table 5 – Thermal L2 Visual Attributes

Attribute	Description
Product components and format	Single Frame Image - Image TIFF Usable Data Mask - TIFF Full Resolution - PNG Stacked Experimental Image – Image TIFF Metadata - GeoJSON
Number of frames	1 (averaging 25 frames within the acquisition)
Product framing	Scene
Product orientation	Sensor orientation
Pixel units	Digital Numbers
Bit depth	14 bit
Geometric corrections	Orthorectified
Radiometric corrections	NUC, Flat Field Correction, Noise Correction
GSD	3.5 – 7 m
Geometric accuracy	30 m CE90

6. Imagery acquisition

6.1 Tasking overview

To facilitate access to newly acquired HotSat thermal imagery, we offer several options for tasking our satellite to meet specific mission requirements and collection timeframes. Customers can use SatVu's tasking tools programmatically via our API or through our human-in-the-loop web interface. With an active tasking contract, users can fully manage their own HotSat task orders.

Placing a tasking order begins with defining the location of interest, acquisition dates, and other collection parameters. A feasibility check is available to ensure all desired task order parameters are viable. Once an order is accepted, new imagery can be scheduled, acquired, downlinked, processed, and delivered within hours.

7.2 Available tasking tiers

Standard tasking – Users can define the full set of tasking parameters, specify the target geometry, and timeframe, as well as the off-nadir angle, ground sample distance, cloud cover percentage and day or night acquisition mode. Standard task orders are added to the satellite plan at a nominal priority level, are planned after higher priority orders, and subject to aggregation with other standard requests.

Assured tasking - Users select the specific pass of the satellite over the desired target area of interest with the time, date, off-nadir angle, and GSD already established by the pass geometry. We capture the image based on the selected opportunity and deliver it, regardless of cloud cover. This product has the highest priority level in the general tasking system.

All levels of tasking are available via our API and web interface. Additional details on tasking and collection processes can be found in **SatVu documentation**.

7.3 Forward-motion compensation

SatVu's HotSat platform uses a ***forward-motion compensation*** (FMC) mode which allows the satellite to point and stare at a particular location over a prolonged period. This mode is used to capture still images or video at up to 25 frames per second (FPS), providing up to 60 seconds of video for a particular target at extreme roll angles. The platform is also agile, ***capable of moving from one target to another over angles of up to ±45°***.

Figure 6 – Forward-Motion Compensation

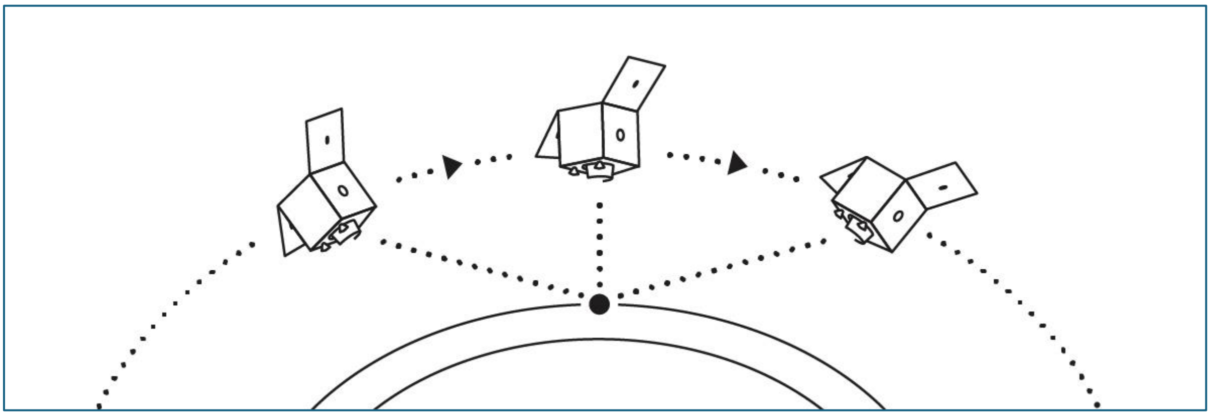

Figure 6 - Forward Motion Compensation of HotSat satellite

Table 6 - Tasking parameter specifications

Parameter	Standard Tasking	Assured Tasking
Location	User Defined	User Defined
Priority	Standard	Highest
Date	User Defined Range	User Selected
Off-Nadir angle	User Defined (0-45°)	Based on selected pass

GSD / Resolution	User Defined (3.5 - 6.8m)	Based on selected pass
Imaging mode	User Defined (Day / Night)	Based on selected pass
Allowable Cloud Cover	User Defined (15 – 100%)	100 %
Delivery	Only when order parameters are fulfilled	Always*
Coverage	Guaranteed 3 km^2 around user defined location (entire 15 km^2 image scene is delivered).	
Service level	Standard Delivery: Within 12 hours from acquisition, 95 % of the time.	
Cancellation	Order Cancellation is available, free of charge, no less than 24 hours prior to scheduled acquisition.	

7. Glossary

Altitude and Orbit Control System (AOCS)

The Altitude and Orbit Control System (AOCS) creates and manages the telemetry logs and information for images captured and downloaded from the satellites.

Area of Interest (AOI)

An Area of Interest (AOI) is a specific geographic area defined by coordinates or boundaries, which is the focus for data collection.

Atmospheric Correction

Atmospheric correction is the process of correcting for the effects of the atmosphere on images taken by satellites or airborne sensors. This uses an atmospheric model and is susceptible to variation to the atmosphere during an acquisition. This process is important because atmospheric constituents like water vapor, aerosols, and gases can distort the signals captured by sensors.

Azimuth

From the scene target point on the ground, the Azimuth is the angle between true north and the sub-satellite point / nadir (point on the ground directly below the satellite). Measured clockwise from north in degrees (0-360).

Calibration

For a thermal imager or radiometer this is often carried out by placing the instrument to view a reference blackbody target. The blackbody target will then be set to a range of temperatures to build a Signal Transfer Function relating the instrument measurement with that from ITS-90.

CE90

Circular Error (CE) is a metric used to define the quality of the geometric accuracy of an image, where 90% of the points in the image are within the stated accuracy

Cloud Cover (%)

The percentage of the scene obscured by clouds. Cloud cover can affect the quality and usability of satellite images.

Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) is a digital 3D ground model, including the maximum altitude in every point, with human superstructures and canopy.

Elevation

The angle of the object (such as the satellite) above the horizon from the perspective of the target point of the scene. It is measured from the horizon in degrees (-90 to 90), with negative values indicating the object is below the horizon.

Feasibility Check

A feasibility check is the process of evaluating if the tasking order with provided parameters can be captured. The check enables better planning of acquisitions by evaluating the current satellite position, its orbit, weather conditions and other forms of data to inform if the tasking order is like to be successful.

Forward Motion Compensation (FMC)

Forward-motion compensation (FMC) mode allows the satellite to point and stare at a particular location over a prolonged period and is used to capture still images or video at up to 25 frames per second (FPS), providing up to 60s of video for a particular target at extreme roll angles.

GeoJSON

GeoJSON is an open standard format for communicating geospatial data. It is based on the JavaScript Object Notation (JSON) text-based data interchange format, often used in web applications for mapping and spatial data exchange.

Georeferencing

Georeferencing is the process of relating the coordinate system of an image to a geographic coordinate system, which allows you to see the image in its correct location on the globe.

Geospatial Data

Information associated with a specific location on the Earth's surface, including coordinates, maps, and satellite imagery.

GeoTIFF

Geographic Tagged Image File Format (GeoTIFF) is a file format which is widely used for Earth observation data because it allows spatial information to be included with raster data.

Ground Control Point (GCP)

Ground Control Points are specific, identifiable, and clearly marked locations on the Earth’s surface with geographic coordinates used to align satellite imagery during the process of georeferencing.

Ground Sample Distance (GSD)

Ground Sample Distance is the distance between two consecutive pixel centres measured on the ground. It is impacted by the off-nadir angle, with a higher off-nadir angle resulting in a higher GSD.

Metadata

Metadata is the information that describes the content, quality, condition, and other characteristics of the geospatial data, helping users understand and use the data appropriately.

Mid-wave Infrared (MWIR)

Mid-wave infrared (MWIR) is the portion of the electromagnetic spectrum which contain the SatVu imaging wavebands.

Nadir

Nadir represents the point directly below the satellite, where the sensor is looking straight down at the Earth's surface.

Non-Uniformity Correction (NUC)

Non-uniformity Correction (NUC) is the process of placing a uniform source in the field of view of the thermal imaging detector to enable the gain and offset for each pixel to be normalised.

Off Nadir Angle (ONA)

The angle between the nadir (directly below the satellite) and the point on the ground being imaged, used to describe the sensor's position relative to nadir. The larger the off-nadir angle when taking an image, the further the satellite can be from the order and still successfully capture it.

Onboard Calibration

SatVu's HotSats, have the capability to perform a calibration using the heated paddles in the target wheel onboard the sensor. These targets can be heated up to 50 °C to enable a signal transfer function to be evaluated.

Order

An Order represents a customer request for imagery from the SatVu platform. This could be an order from the Catalog, or a Tasking order. Each order has a unique ID and can be viewed or managed in the SatVu platform.

Orthorectification

The process of correcting the sensor, satellite/aircraft motion and terrain-related geometric distortions in satellite or aerial imagery to accurately represent the Earth's surface.

Parallax Shift

Parallax shift is the apparent shift in position of an object when the observer's position changes.

Portable Network Graphics (PNG)

Portable Network Graphics (PNG) is a widely used image storage format which can be easily viewed across a range of computer operating systems.

Point of Interest (POI)

The Point of Interest (POI) is the specific location or feature on the Earth’s surface that is of interest within a scene, or for tasking the satellite.

Polar Orbit

A polar orbit is one in which a satellite passes above, or nearly above, both poles of the body being orbited on each revolution. Polar orbits provide near-global cover and is particularly valuable for consistent monitoring of both the Arctic and Antarctic regions.

Raster Data

Geospatial data represented by a grid of cells or pixels, where each cell contains a value representing specific information, such as thermal signature.

Radiometric Processing

Radiometric processing represents the variety of techniques that involve correcting, converting, or calibrating pixel values of a raster data set to a desired solution from its current or native state.

Scene

A single image or frame captured by a satellite or sensor, characterised by a specific AOI at a given time.

Signal

Signal measured by the HotSat payload uses digital number units. This pixel response is proportional to the radiance delivered to each pixel (see signal transfer function).

Signal Transfer Function (SiTF)

Signal Transfer Function describes the relationship between measured signal and a calibrated apparent radiance. This dependence is not restricted to solely digital number and may include additional terms such as the focal plane array temperature or integration time.

Spatial Resolution

The size of the smallest object that can be detected in an image, where higher resolution means finer detail. For satellite imagery, the spatial resolution is often represented by the Ground Sample Distance (See GSD above).

Spatial Temporal Asset Catalog (STAC)

Spatial Temporal Asset Catalog (STAC) is a standard specification used to store and describe geospatial information.

Spectral Resolution

The ability of a sensor to distinguish between different wavelengths of light, allowing for the identification of various materials or phenomena. The SatVu sensor captures the mid-wave infrared (See MWIR above) region of the electromagnetic spectrum.

Spectral Response Function (SRF)

The Spectral Response Function (SRF) maps the signal arriving at the sensor, to signal readout from the sensor. This is wavelength dependant based on the integral of the spectral radiance of signal. A unique spectral response will be present for each optical path for a system where multiple lens paths or filters may be in use.

Sun Azimuth

From the scene target point on the ground, this is the angle between true north and the sun. Measured clockwise from north in degrees (0-360).

Sun Elevation

The angle of the sun above the horizon from the perspective of the target point of the scene. It is measured from the horizon in degrees (-90 to 90), with negative values indicating the sun is below the horizon.

Tasking

Satellite tasking is the process of requesting a new image collection.

Users can task a SatVu sensor to capture a new image by specifying a location, time frame, and other parameters.